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MOBILE SOURCE CONTROL DIVISION
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**DEVELOPMENT OF HOURLY VEHICLE ACTIVITY FOR
ESTIMATING VEHICLE EMISSIONS**

By

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SEVENTH CRC ON-ROAD VEHICLE EMISSIONS WORKSHOP
San Diego, California, April 9-11, 1997

ABSTRACT

As part of a continuing effort to improve the accuracy of the State of California's Motor Vehicle Emissions Inventory (MVEI) model, the Air Resources Board (ARB) will be disaggregating vehicle activity into 24 periods. Over the past several years, most of the efforts associated with improving the MVEI model have been with developing highly resolved emission factors. Now an effort is being made to match the new emission factor modeling results (e.g. continuous starts, partial hot soaks, and multiday diurnals) with more resolved activity data. The current version of the MVEI model, MVEI7G, separates vehicle activity into 6 uneven time periods which are designed to reflect peak and off-peak periods of driving. Second-by-second vehicle activity data was collected by the United States Environmental Protection Agency (EPA) and the ARB in Baltimore, Maryland; Spokane, Washington; Atlanta, Georgia; and Los Angeles, California. To date, EPA's three city data and ARB's Los Angeles data has primarily been used to develop new driving cycles. However, these data collection efforts were also designed to obtain highly resolved vehicle trip activity data. This paper will present the results of analyzing vehicle trip characteristics such as time-on and off, the number of trip-starts and ends, speed distribution, resting time, and vehicle miles traveled (VMT) for each individual city. An analysis of the data shows that the driving characteristics between the four cities are similar with slightly different driving patterns for Los Angeles.

INTRODUCTION

The ARB is currently under contract with Sierra Research, Inc., to improve the MVEI model. This new model is currently referred to as EMFACX while in the development stage. Some of the changes will be to the activity portion of the MVEI model. These changes are being incorporated to reflect the more resolved emission factors that are available for running, starting, and evaporative emissions. Previously, vehicle activity in the MVEI model was characterized into

6 uneven time periods. The new activity estimates will not only disaggregate activity into 24 hourly time periods, but within each period the driving characteristics will be further disaggregated. For example, a trip with a given mean speed will not only be assigned to the hour that the trip started but also to the appropriate mean speed bin. In MVEI7G, the number of trips were assigned to a given time period, whereas for EMFACX the trip's duration will also be assigned to the period. Therefore, not only are the periods more resolved but an additional dimension will be added to the complexity of the activity matrix. Previous analyses by the Radian Corporation, under contract to U.S. EPA, have evaluated trip characteristics using the Baltimore and Spokane data, but like the current model, the analyses were aggregated into 6 uneven time periods¹.

The second-by-second instrumented vehicle data collected by the U.S. EPA and the ARB for the cities of Baltimore, Maryland; Spokane, Washington; Atlanta, Georgia; and Los Angeles, California will be used to characterize trip activity. The data from the ARB and U.S. EPA instrumented vehicle projects may contain trips which are not necessarily representative of typical driving, therefore these driving events were removed from the analyses. For example, in the U.S. EPA datasets the vehicles were instrumented at an I/M test facility, thus the first and last day of driving may not be representative of how the owners of the vehicles may drive their vehicles because they may have shortened or altered trips for those days. Therefore, the first and last days of driving were deleted. However, they were used when calculating information for the second day of driving (i.e. soak time) and the day before the last day of driving (i.e. driving which starts on the second to the last day of driving and continued into the last day). In addition, the Atlanta instrumented vehicle dataset had several errors within the collected data. Some of the problems included: data only collected at two second intervals for a vehicle exchange or individual trip, and some trips had missing speed data. For these vehicles, the entire vehicle exchange was deleted instead of the individual trip because deleting trips would cause erroneous extended soaks, decreased trips per day, and decreased VMT for this methodology. Similarly, the ARB dataset contained several vehicle exchanges with missing speed data, and those exchanges were also deleted.

The trip characteristics which were being developed for EMFACX include time-on, time-off, trip-starts, trip-ends, speed frequency distribution, resting time frequency distribution, VMT, and a speed-VMT-hour frequency distribution. Descriptions of the above variables were defined prior to analyzing the data as follows:

Definitions of Activity Variables

Time-on

For programming purposes, time-on will be used for estimating exhaust emissions. Time-on is the length of time a vehicle was running during the respective hour. If a vehicle's running time overflows into the next hour all of the time is counted in the hour where the vehicle started. An example of this would be a vehicle which was started at 3:59 p.m. and shut off at 4:15 p.m. The total operating time of 16 minutes would be applied to the 3:00 p.m. hour. A two-dimensional time-on frequency distribution was also analyzed. The

time-on frequency distribution was determined by binning the time-on events from one minute to two hours for each hour of the day.

Time-off

Time-off will be used to calculate starting emissions in EMFACX. Time-off is the amount of time the vehicle is off (or soaking) prior to a trip-start, and this event is applied to the hour that the start occurred. For example, say a vehicle was parked and turned off at 5:00 p.m. and then restarted at 7:00 a.m. the next day. This 14 hour time-off event would be applied to the start hour of 7:00 a.m. This time-off should be used in calculating the starts correction factor. A two-dimensional time-off frequency distribution was also determined by binning the time-off events from 5 minutes to 4 days for each hour of the day.

Trip-Starts

Trip-starts will be used to determine the hourly trip distribution in EMFACX. The number of trip-starts is the number of times an instrumented vehicle was started during the respective hour. For example, a key-on event at 3:59 p.m. by a vehicle would be counted as a start during the 3:00 p.m. hour. If a vehicle apparently stalled and was restarted within 15 seconds then it was considered as only one start or trip.

Trip-Ends

Trip-ends will be used in estimating evaporative emissions in EMFACX, and it is calculated by determining the number of times a vehicle ended its trip (key-off) during a respective hour. For example, consider the same trip-start as mentioned above with the trip starting at 3:59 p.m. and ending at 4:15 p.m. In this case, a single trip-end count would be applied to the 4:00 p.m. hour.

Speed Frequency Distributions

To estimate running exhaust emissions and running evaporative losses for EMFACX, a two-dimensional frequency distribution was developed for mean speed by hour of the day. The speed distribution was determined by taking each trip's mean speed and then assigning it as a single count to the appropriate speed bin, i.e. 0-1 mph speeds are assigned to the 0 mph bin, 1-5 mph are assigned to the 5 mph bin, 5-10 mph is assigned to the 10 mph bin, and so on. This was done for each hour of the day.

Resting Time Frequency Distributions

The resting time frequency distributions matrix will be used for estimating evaporative emissions (i.e. hot soaks, diurnal, and resting losses) for vehicles at rest in EMFACX. The resting time distribution is the amount of time a vehicle will be off and is applied to the hour that the trip ended. This is in contrast to time-off, which is applied to the start of the trip. Each trip has a resting event and it is assigned to the respective resting time bin for the hour that the trip-end occurred. The bins ranged in time from five minutes to 4 days.

Vehicle Miles Traveled

VMT is the distance traveled by a vehicle during a trip and is assigned to the respective hour. If a trip spans more than one hour, then the distance will be assigned to the initial

hour for which the trip started. The distance was calculated from speed on a second-by-second basis using the equation $\text{distance} = \text{speed} \times \text{time}$. A two-dimensional VMT by hour of the day frequency distribution was analyzed. The VMT frequency distribution was determined by binning the distance of each trip. For example, 0-1 mile trips were assigned to the 0 mile bin, 1-5 mile trips were assigned to the 5 mile bin, 5-10 mile trips were assigned to the 10 mile bin, and so on.

Speed-VMT-Hour Frequency Distributions

A three-dimensional speed-VMT-hour frequency distribution was also developed for calculating running loss and hot soak emissions. The same binning methods were used for mean speed and VMT.

Throughout this paper, most of the analyses are simplified and shown as two-dimensional graphs. In actuality, the input matrices for the EMFACX model will include two- or even three-dimensional matrices, thus requiring three- or four-dimensional graphs. For example, the speed distribution matrix will contain the frequency distribution by hour of the day and by mean speed bin. Graphs representing all of the two- and three-dimensional matrices are shown in Appendix A and B, respectively.

DISCUSSION

Time-On and Time-Off

Distributions of percent time-on and time-off for Atlanta, Baltimore, Los Angeles, and Spokane are shown in Figures 1 and 2, respectively. Time-on was calculated by summing the time-on for all vehicles during the respective hour and then dividing by the total time for all hours. As expected, there is an increase in time-on for the morning commute and a decrease in the amount of time-on prior to the noon hour. At approximately the noon hour, the length of time-on increases again and then stabilizes until approximately 5:00 p.m.. As shown in Figure 2, there is an increase in the time-off from approximately 4 a.m. to 10 a.m. This is probably due to starts occurring during these hours and because the time-off is applied to the time the vehicle was started. The amount of time-off was calculated from when a vehicle ended its last trip, and multiple soak days were also included in the data analysis and applied to the respective hour. Although the data analyzed shows these increases in time-on and off for the morning commute, it should be noted that the number of events used to calculate the rates prior to 6 a.m. were fewer in occurrence than were used for the peak morning commute hours. Even with this relative scarcity of data, which is expected during these hours, the increase in time-on and off prior to the morning commute does seem reasonable when compared to the rates estimated for after 6 a.m.

A composite distribution of time-on and time-off was developed for incorporation into EMFACX by combining the data from the four cities. The composite time-on and time-off distribution is shown in Figure 3. Although the current data shows that time-on and time-off for Los Angeles is different than for the other three cities, it was still combined because, as mentioned earlier, not all of the data from the Los Angeles dataset was available. In addition, it is believed that more than one type of activity profile may eventually be needed to represent cities in California because of this difference. Los Angeles, being a large metropolitan area, may have driving events other cities may not have. For example, there is a larger percentage of time-on and time-off events in the

early morning hours between 1:00 a.m. and 4:00 a.m.. These increases could be due to factors such as people working graveyard shifts, alternate work schedules, or starting a commute in early

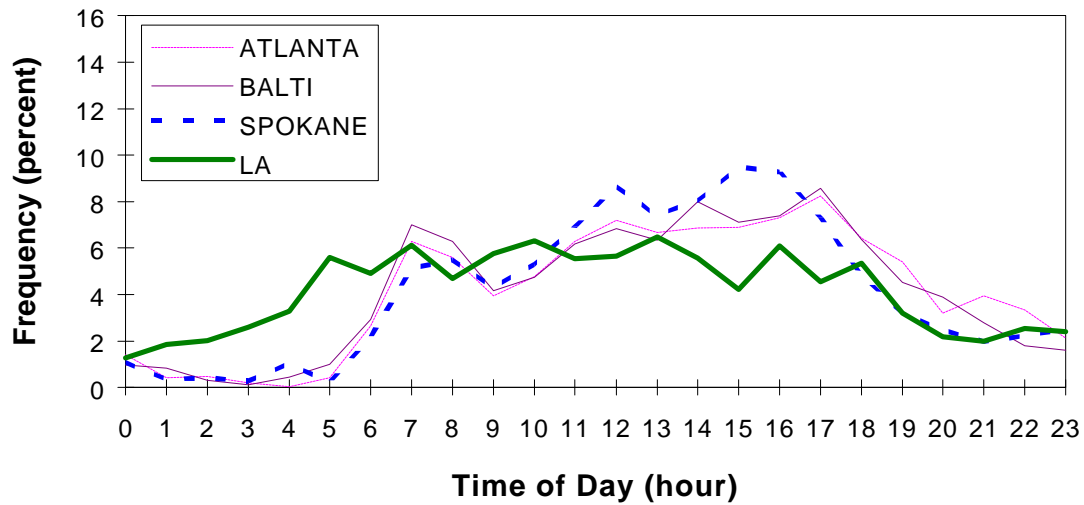


Figure 1. Time-On Distribution for Trips in Atlanta, Baltimore, Spokane, and Los Angeles.

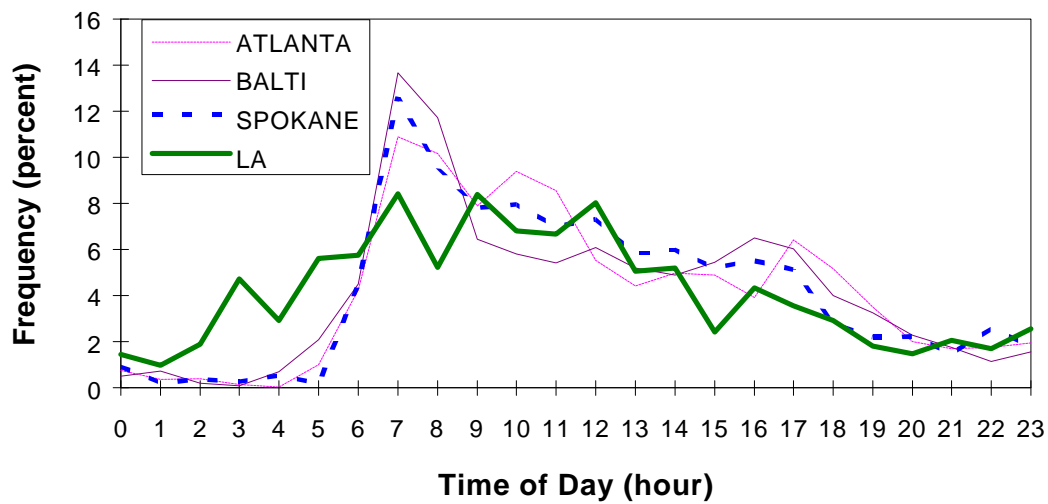


Figure 2. Time-Off Distribution for Trips in Atlanta, Baltimore, Spokane, and Los Angeles.

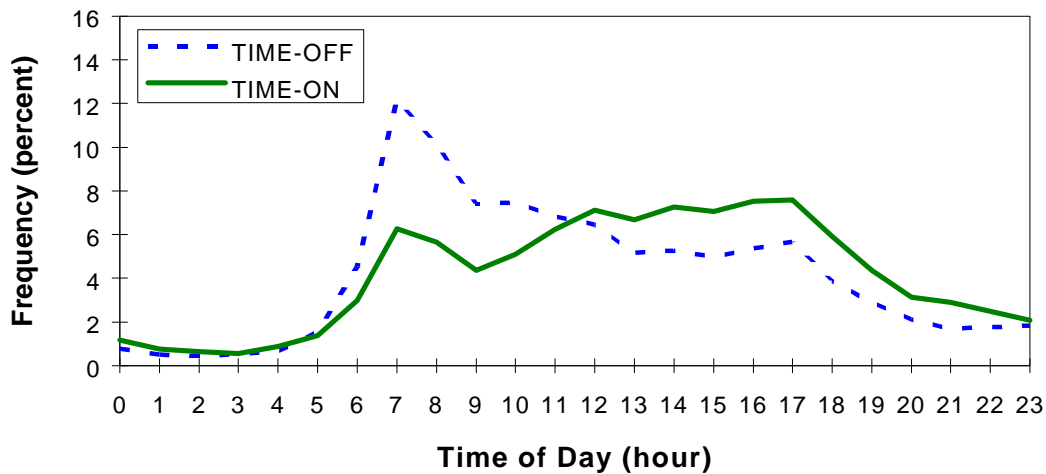


Figure 3. Combined Time-On and Off Distribution.

morning. For example, one reason why there may be a larger percentage of vehicles beginning trips between 1:00 a.m. and 5:00 a.m. in Los Angeles is because of the longer commute distances in Southern California relative to other parts of the U.S.. Approximately, 71,000 vehicles make a regular commute from San Bernardino and Riverside areas to the Los Angeles area². These commuters are presumably starting their early morning commute to avoid traffic and because they have to travel a long distance.

The time-on and time-off frequency distributions matrix by hour of the day and duration are shown in Figures A-1 and A-2 of Appendix A. These time-on and time-off distribution matrices will be used in EMFACX.

Resting Time

Resting time is similar to time-off, however, the amount of time off is applied to the end of the trip. Figure 4 compares the distribution of resting times for each of the four cities. The resting time trends for the four cities show better agreement than the previous figures for time-on and time-off. Two distinctive increases in the amount of time that a vehicle is at rest occurs between the hours of 7:00 a.m. and 8:00 a.m. and then between the hours of 2:00 p.m. and 7:00 p.m.. The first increase in resting time coincides with the end of a typical morning commute, and probably reflects an increase in resting time while the vehicle's owner is at work. The latter coincides with the afternoon commute and appears to be occurring when the vehicle reaches its final resting place. The time span for the increase in frequency for the afternoon commute is much longer than for the morning commute. This longer time span may be due to factors such as alternate work week schedules, running errands after work, picking up kids after school, etc. The Atlanta resting time distribution seems to have a more predictable trend corresponding to morning commute, lunch commute, and a final afternoon commute. The Atlanta afternoon commute starts later than for the other cities and the duration of the increase in resting time is shorter. A composite resting time distribution was also developed and is shown in Figure 5.

A composite distribution of resting time by hour of the day and duration is shown in Figure A-3 of Appendix A. This resting time distribution matrix will be used in EMFACX.

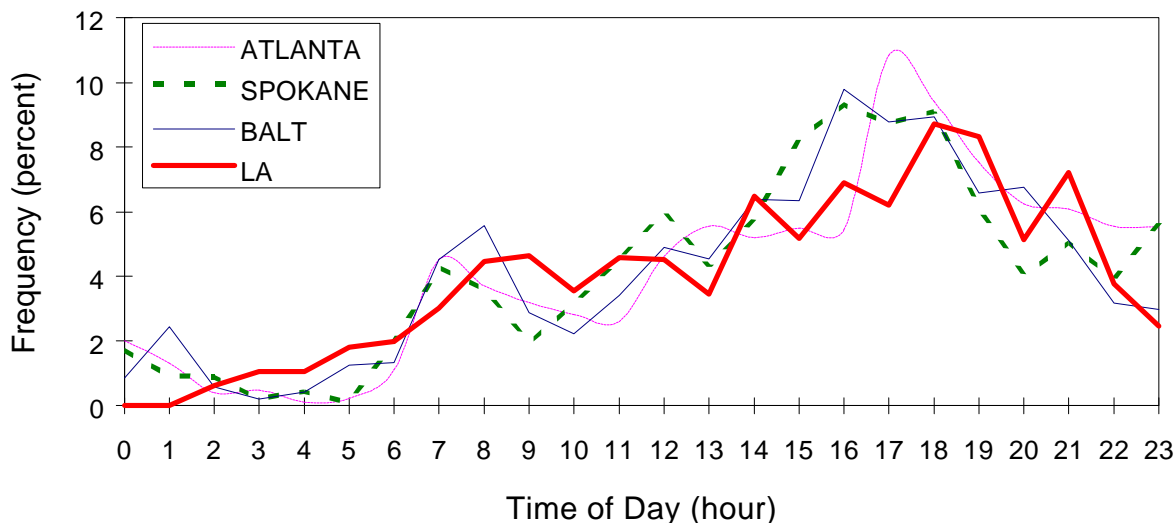


Figure 4. Distribution of Resting Time for Atlanta, Baltimore, Los Angeles, and Spokane.

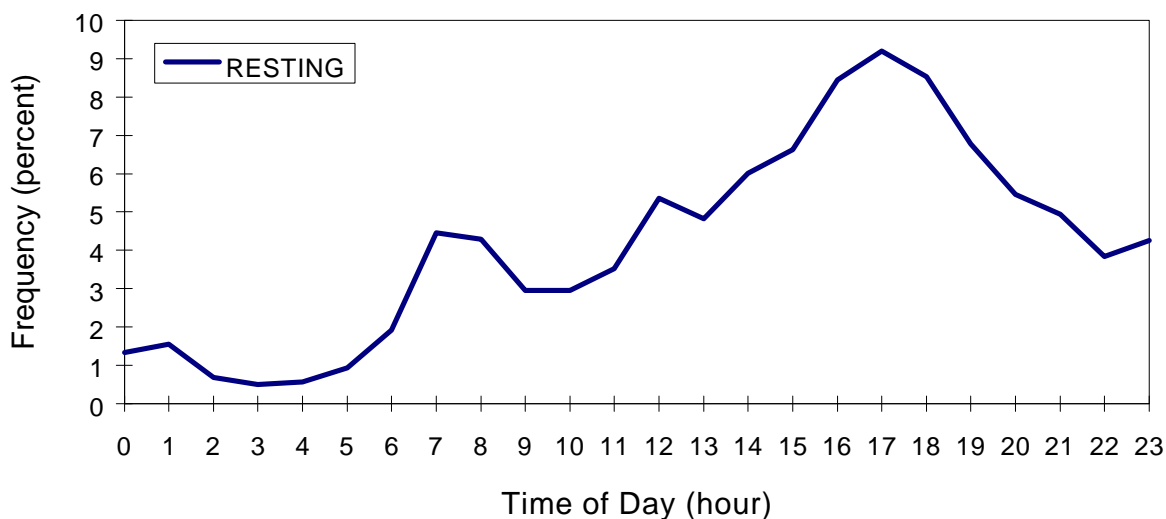


Figure 5. Combined Resting Time Distribution.

Trip-Starts and Trip-Ends

The frequencies of trip-starts and trip-ends were determined on an hourly basis and are shown in Figures 6 and 7. For this analysis, the frequencies of trip-starts and ends for a given hour were defined as the total trips (starts or ends) for all hours divided into the total trips (starts or ends) for that given hour. As it can be seen by the figures, similar results for trip-starts and trip-ends were produced. This result is not surprising since most trips are less than an hour in length, thus ending in the same hour as the trip originated. The relatively small deviations from trip-starts and ends are the result of trips crossing different hours of operation. There are two distinct trip episodes, one for the morning commute and then an additional increase in trips for midday,

starting at approximately 11 a.m. These results show that the “typical” go-to-work and then go-to-home commuter does not exist, unless they are going home at lunch time. A substantial percentage of trips are occurring between 11 a.m. and 6 p.m. The specific reason for this increase is unknown, however, it is believed people are trying to accomplish multiple errands during the lunch hour or during the afternoon hours.

Figure 8 compares the combined trip-start and trip-end profiles for EMFACX to the current trip-starts estimate for MVEI7G. To compare composite trip-starts to the estimates from MVEI7G, the percentage of trip-starts for each period had to be evenly distributed within the period. The two trip-start profiles show reasonable agreement even though MVEI7G divides trip-starts into 6 uneven time periods³.

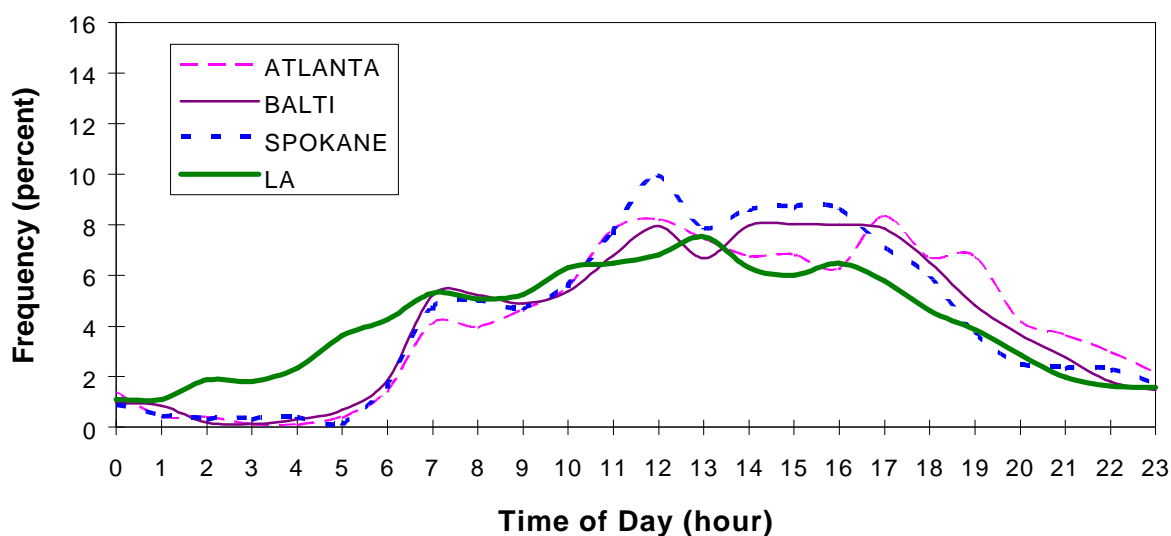


Figure 6. Distribution of Trips-Starts for Atlanta, Baltimore, Los Angeles, and Spokane.

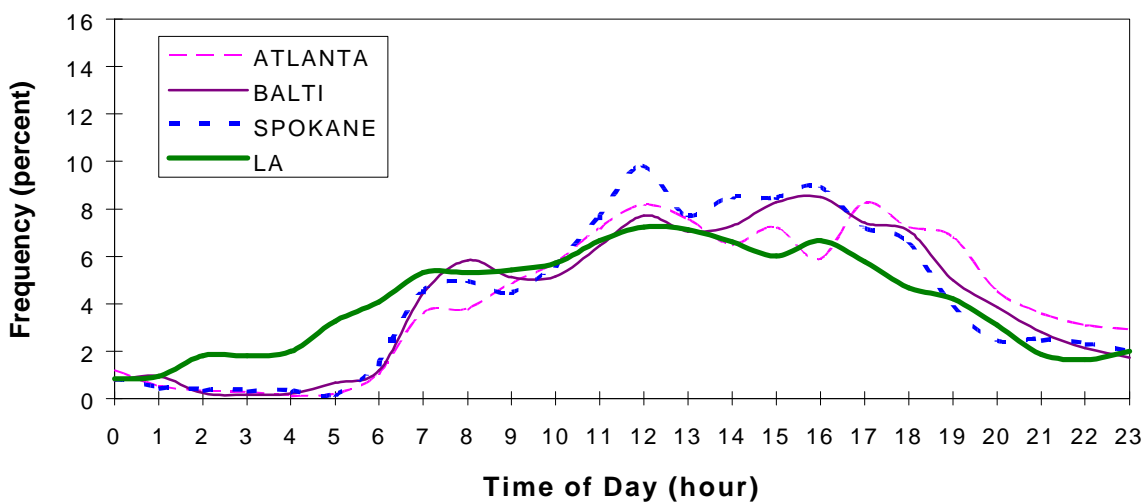


Figure 7. Distribution of Trips-Ends for Atlanta, Baltimore, Los Angeles, and Spokane.

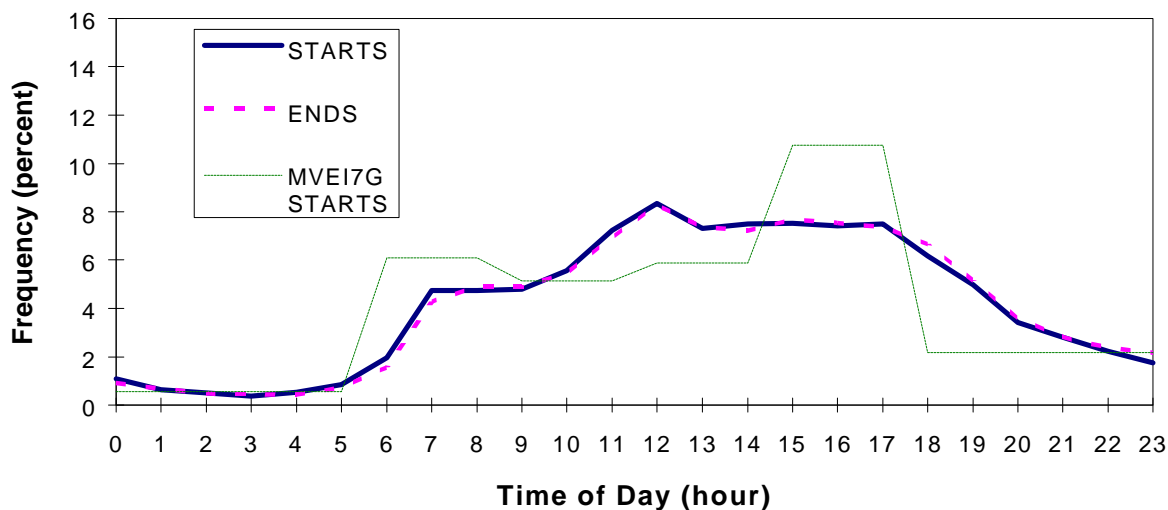


Figure 8. Combined Trip-Start and Trip-End Distribution Compared to MVEI7G.

Vehicle Miles Traveled

The distribution of VMT by time of day for the four cities was also determined and is shown in Figure 9. The composite VMT results and the current VMT estimate for MVEI7G are shown in Figure 10. The total VMT for each hour is the distance traveled by all vehicle trips which started during that hour. Like the distribution of trip-starts and trip-ends, there is an increase in the VMT for the morning commute and then an additional increase during the afternoon hours. The increase in VMT during the morning commute corresponds to the increase in the number of trip-starts of longer duration. In addition, there is an increase in VMT in the afternoon hours which corresponds to the increase in trips of shorter duration. An investigation of the mean distance per trip showed a noticeable increase in the distance per trip for the morning hours relative to the afternoon hours. This increase can be noted in Figures 10 and 11, which show a modest increase in the VMT and a substantial decrease in mean trip time-on during the afternoon hours, respectively.

The composite distribution for VMT by hour of the day and distance is shown in Figure A-3 of Appendix A. This resting time distribution matrix will be used in EMFACX.

Four Dimensional Speed-VMT-Hour Frequency Distribution

The three city dataset was also analyzed to develop a speed-VMT- hour frequency distribution matrix. As before, each trip was analyzed for its mean speed, distance traveled and time at which the trip occurred. A graphical representation of the data is shown in Figure B-1 of Appendix B. For purposes of clarity, the data was divided into 3 hour increments. As shown in the figure and noted earlier, there is an increase in driving events during the afternoon hours. There is also a small increase in the number of trips which have a higher mean speed for a longer distance than during the afternoon hours.

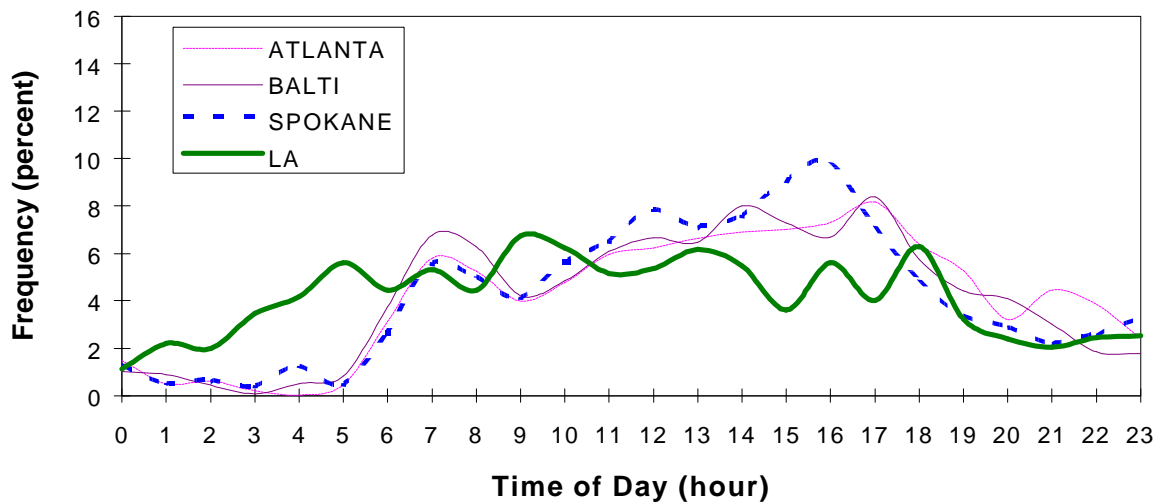


Figure 9. Distribution of VMT for Atlanta, Baltimore, Spokane, and Los Angeles.

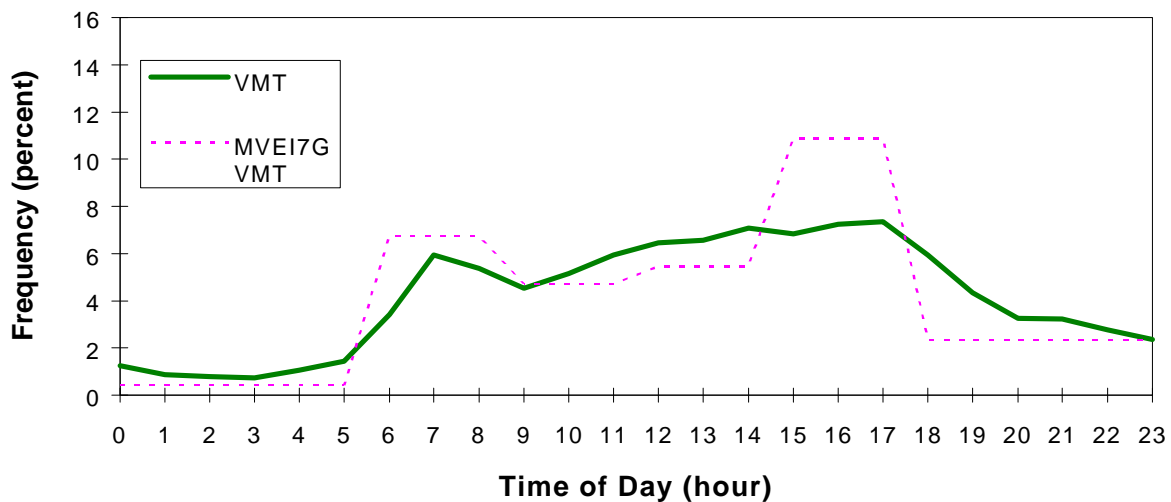


Figure 10. Distribution of Total VMT Compared to MVEI7G.

RECOMMENDATION

Conceptually, the results produced from the data analysis seem reasonably close to how driving patterns occur. Although the data showed slight differences between the U.S. EPA three city dataset and the ARB dataset, it is believed that the four cities should be combined to produce composite activity matrices for inclusion into EMFACX. Further analyses should be conducted to determine if larger metropolitan areas, like Los Angeles, should have a different set of activity matrices compared to other cities within the State.

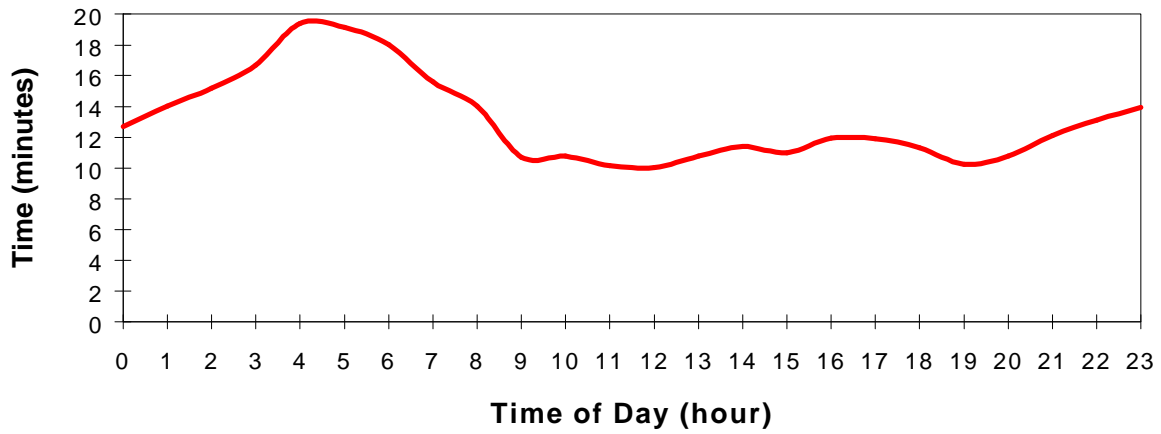


Figure 11. Distribution of Mean Time-On for Atlanta, Baltimore, Spokane, and Los Angeles.

DISCLAIMER

The opinions, findings, and conclusions expressed in this paper are those of the staff and not necessarily those of the Air Resources Board.

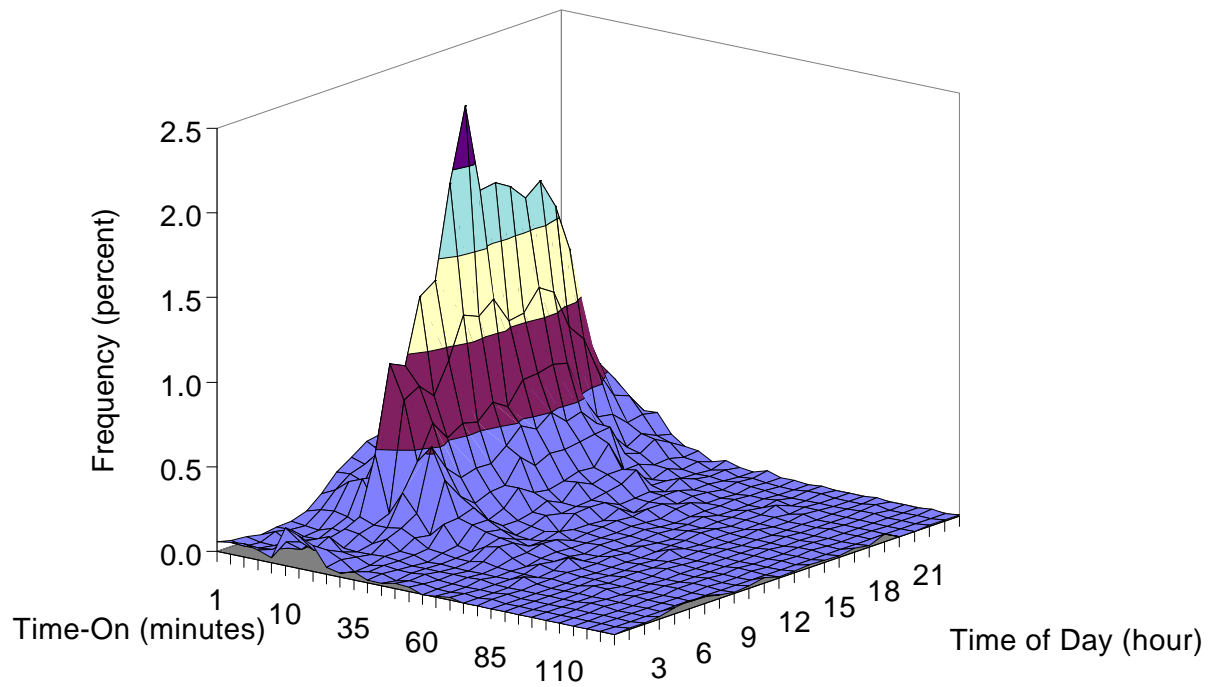


Figure A-1. Distribution of Time-On by hour of day for Atlanta, Baltimore, Los Angeles, and Spokane.

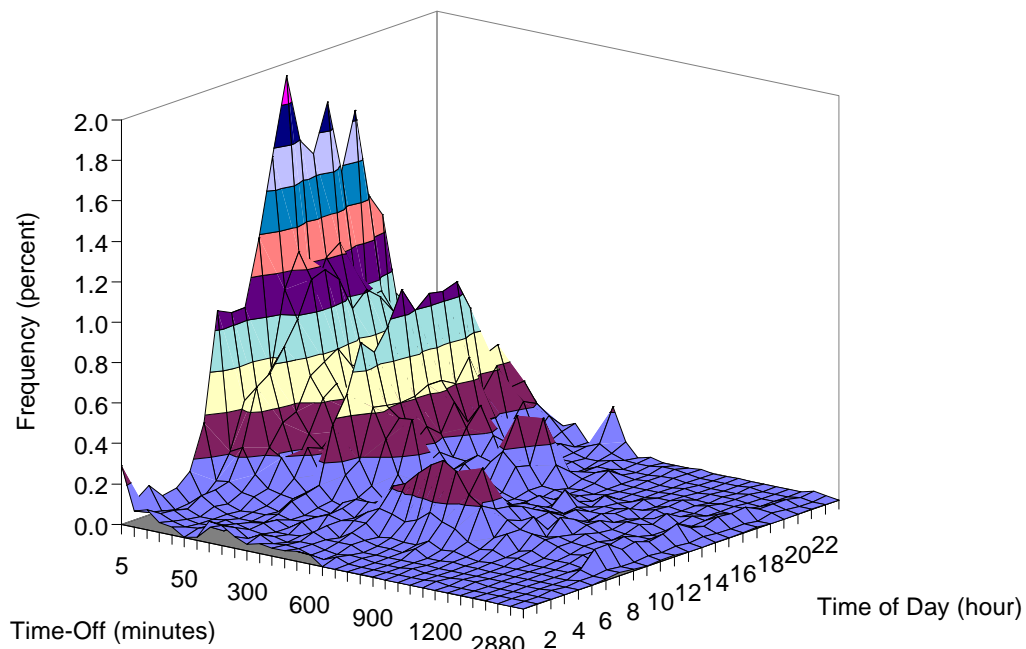


Figure A-2. Distribution of Soak Time by Hour of the Day and Duration for Atlanta, Baltimore, Los Angeles, and Spokane Combined.

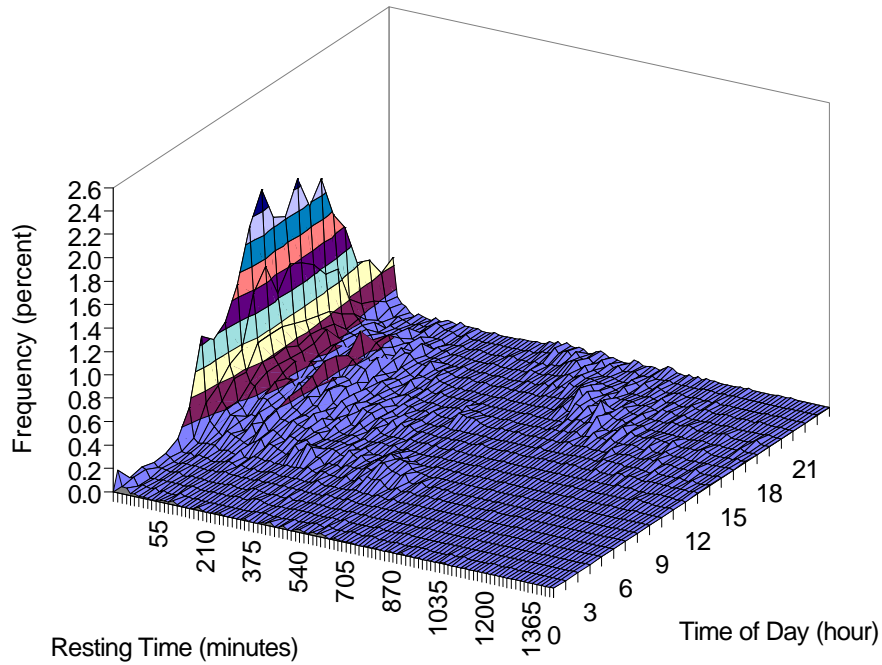


Figure A-3. Distribution of Resting Time by Hour of the Day and Duration for Atlanta, Baltimore, Los Angeles, and Spokane Combined.

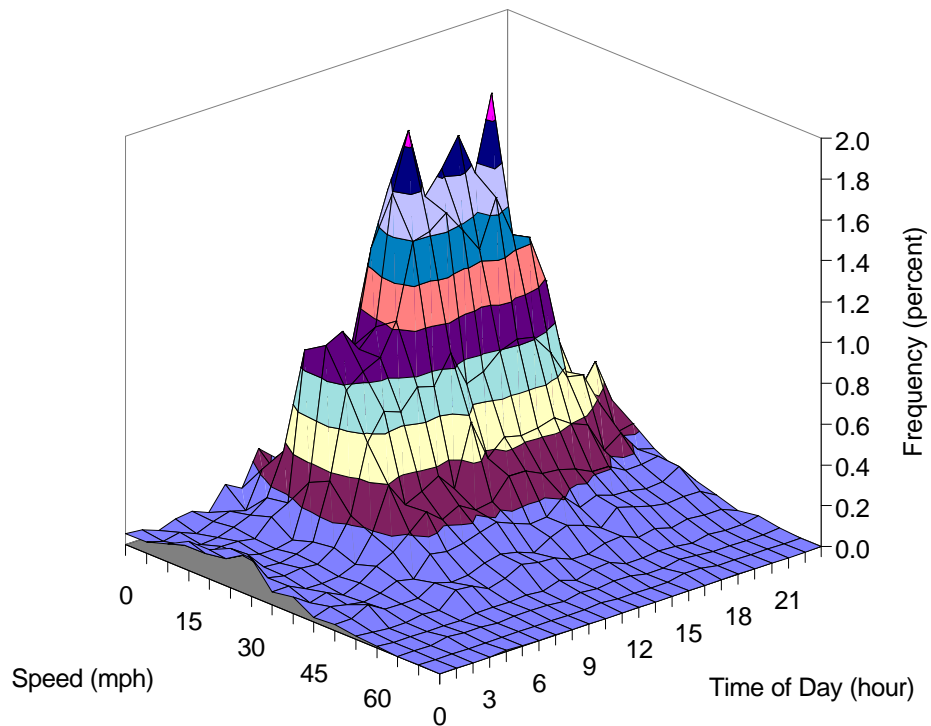


Figure A-4. Trip Speed Frequency Distribution by hour of day for Atlanta, Baltimore, Los Angeles, and Spokane.

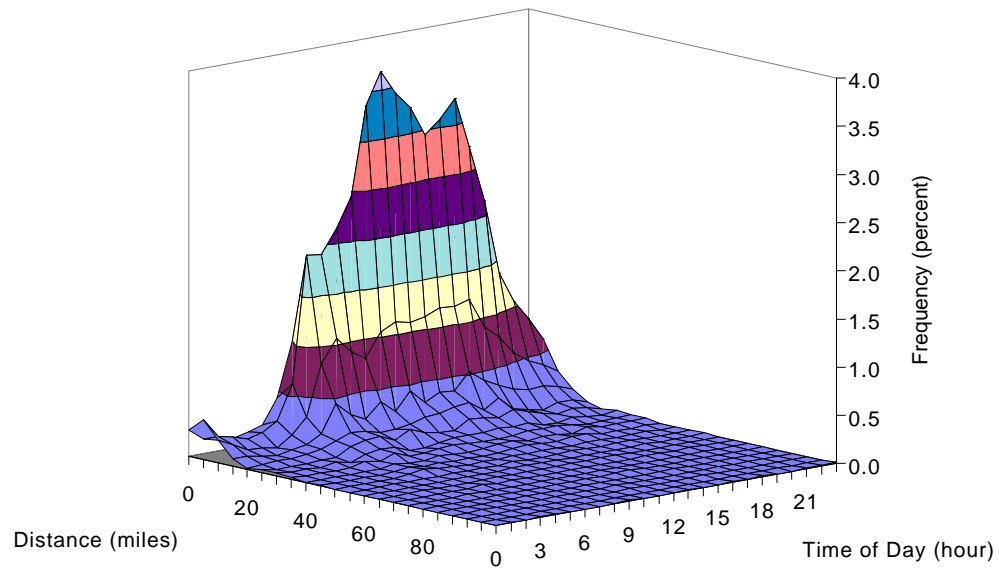


Figure A-5. VMT Frequency Distribution by hour of day for Atlanta, Baltimore, Los Angeles, and Spokane.

APPENDIX B

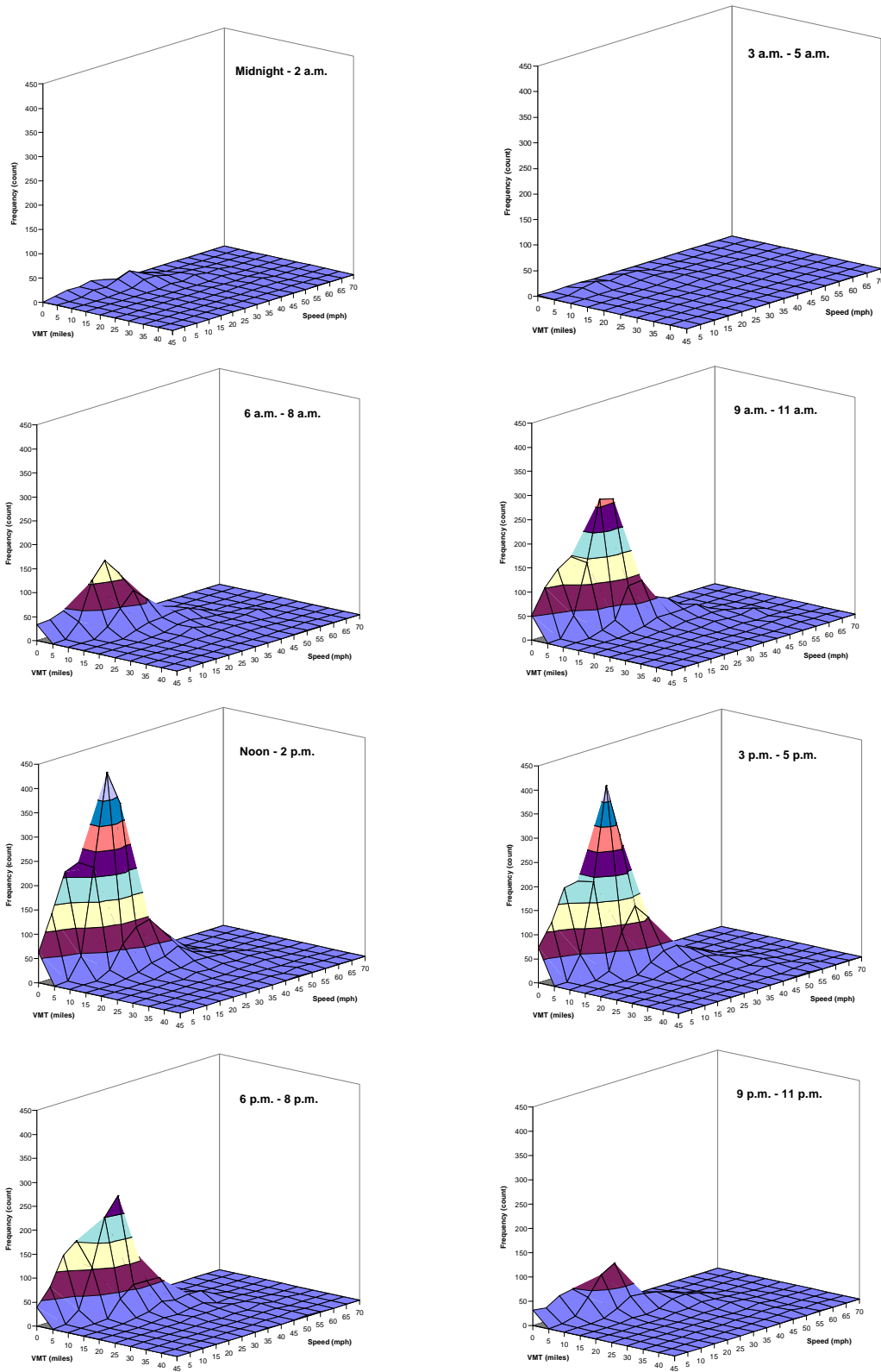


Figure B-1. Speed-VMT-Hour Frequency Distribution for Atlanta, Baltimore, Los Angeles, and Spokane.

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- ¹ T.H. DeFries and S. Kishan, *Light-Duty Vehicle Driving Behavior: Private Vehicle Instrumentation*, Radian Corporation, Draft Final Report to the U.S. EPA, August 24, 1992.
- ² Southern California Association of Governments, *Region Travel Demand Model*, 1994.
- ³ Air Resource Board, *Methodology for Estimating Emissions from On-Road Motor Vehicles*, November, 1996.